

## Preface

The spectacular improvement in the performance of microelectronic devices has been a major factor in the development of today's high-speed computing. The work described in the first part of this issue of the *IBM Journal of Research and Development* is a small sample of the many efforts underway at IBM and elsewhere to increase semiconductor device and circuit performance.

In the Si-based microelectronics technology, on which we rely heavily, miniaturization has resulted in an increase in performance and packing density—by a staggering amount thus far. Scalability of Si metal-oxide-semiconductor field-effect transistors (MOSFETs) into the  $\mu\text{m}$ -gate-length range was demonstrated at IBM in the early 1970s. Their extendibility to gate lengths down to about  $0.1\ \mu\text{m}$  has now been demonstrated. The first paper, by Sai-Halaszi et al., shows that by using appropriate device design, advanced processing methods, and modified operating conditions, ring-oscillator circuit delays as low as about 13 picoseconds per stage can be achieved at a temperature of 77 K. Although efforts would be required to minimize the effects of the nonscalable aspects of Si MOSFETs (inversion layer thickness, velocity saturation, etc.) and to extend present processing capabilities (toward higher-throughput  $0.1\text{-}\mu\text{m}$ -level lithography, reliable, narrow interconnections and thin gate insulators, etc.), the work of Sai-Halaszi et al. has indicated that there are no fundamental physical phenomena which prevent the scaling of Si MOSFETs to the  $0.1\text{-}\mu\text{m}$  level.

At very small dimensions, nonclassical transport phenomena that may have a significant impact on device performance occur. (An example is the velocity overshoot in short-gate-length FETs discussed by Sai-Halaszi et al.) The second paper, by Laux et al., describes the use of a Monte Carlo transport model for taking such phenomena into account. Making appropriate assumptions regarding band structure and carrier heating, the authors have used the model to simulate the operation of unipolar and bipolar Si and III-V devices at reduced dimensions, thereby providing insight into the design and operation of future high-speed devices.

The papers that follow focus on the use of III-V materials, which offer higher electron mobility and saturation velocity, and considerable heterostructure engineering flexibility. These features make such materials attractive for high-speed devices despite their more difficult process technology. Moreover, the direct bandgaps of many of the III-V materials make them the only viable candidates for fabricating semiconductor lasers and integrated optoelectronic devices.

The first GaAs METal Semiconductor Field-Effect Transistor (MESFET) device was fabricated at IBM in the late 1960s, utilizing the high barrier height of a

Schottky gate on GaAs. The paper by Jackson et al. focuses on two different approaches, used recently at IBM, to fabricate sub- $\mu\text{m}$ -gate-length GaAs MESFETs. Room-temperature ring-oscillator circuit delays as short as 16 ps per stage have been achieved at a gate length of about  $0.3\ \mu\text{m}$ .

Heterojunction FET (HFET) devices formed from layered structures of different III-V materials are reviewed in the paper by Kiehl et al. In this family of devices, transport occurs in a high-mobility, two-dimensional electron gas channel that is physically separated from device dopants. Emphasis is on two types of devices in which use can be made of an undoped, higher-aluminum-content AlGaAs gate barrier, thereby achieving a higher cutoff frequency than has been achieved for other types of HFETs. One, the semiconductor-insulator-semiconductor FET (SISFET), offers a more reproducible threshold voltage but must be operated with a low supply voltage. The other, the quantum-well metal-insulator-semiconductor FET (MISFET), has a more process-sensitive threshold, but operates at higher voltages; it has been realized in both n- and p-channel devices suitable for complementary circuits. Both devices exhibit significantly improved characteristics at 77 K.

A ballistic electron device, still in its infancy, the tunneling hot-electron transfer amplifier (THETA) device, is described in the paper by Heiblum and Fischetti. Currently, the device is used primarily as a research tool for investigating the transport of hot ballistic electrons—the highest-velocity electrons that can be obtained in a solid. Versions of the device have been fabricated in a vertical and, more recently, a lateral configuration. The investigations have shown that large fractions of injected electrons can be transported ballistically through GaAs and InGaAs layers. At small enough dimensions, size-quantization effects become significant. Ballistic hole transport has been observed in a similar p-type device.

While high speeds can be obtained at the device level and also at the unloaded ring-oscillator level using the above-described FET and hot-carrier devices, bipolar devices, because of their superior current drive capability, are usually faster, albeit at higher power dissipation levels, in a typical VLSI circuit environment—especially when large loads must be driven. However, scaling bipolar transistors to very narrow emitter and ultrathin base widths remains a challenge. In that regard, the use of heterojunctions may begin to play a significant role. The first III-V heterojunction bipolar transistor (HBT) was fabricated at IBM in the early 1970s using liquid-phase epitaxy. In their paper, Tiwari et al. discuss III-V HBTs. The authors emphasize the technological advances and physical limits of these devices (including improved

ohmic contacts and the effects of surface recombination) and provide a critical evaluation of the material parameters of GaAs on which their ultimate performance and scalability depend. Although Si bipolar devices are not covered in this issue, recent work on SiGe heterostructures, especially HBTs with a SiGe base, offers the exciting possibility of incorporating heterojunctions and bandgap engineering into the Si device technology.

Optoelectronics and its integration into VLSI will certainly be important in the future. Associated considerations are the larger bandwidth and higher speed as well as the greater noise immunity of optical communication channels. The paper by Harder et al. describes some of the authors' relevant work on laser diodes and high-speed photodetectors. The focus is on the technology and performance of AlGaAs quantum-well laser diodes with low threshold. The authors also

report a GaAs metal-semiconductor-metal detector with a  $-3$ -dB bandwidth of 105 GHz.

The advances in high-speed computing over the past several decades have occurred because of impressive increases in device speed and reductions of interconnection delays at the chip and package levels. The papers in this issue indicate that impressive increases in device speed will probably continue to occur in the years ahead.

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